(2007, pp. 1,533–1,536) concluded: ''These results provide strong evidence that, despite prominent contributions of natural variability in the observed record, GHG loading has played a role.''

Hegerl et al. (2007) used a new approach to reconstruct and attribute a 1,500-year temperature record for the Northern Hemisphere. Based on their analysis to detect and attribute temperature change over that period, they estimated that about a third of the warming in the first half of the 20th century can be attributed to anthropogenic GHG emissions. In addition, they estimated that the magnitude of the anthropogenic signal is consistent with most of the warming in the second half of the 20th century being anthropogenic.

Observed Changes in Other Key Parameters

Snow Cover on Ice

Northern Hemisphere snow cover, as documented by satellite over the 1966 to 2005 period, decreased in every month except November and December, with a step like drop of 5 percent in the annual mean in the late 1980s (IPCC 2007, p. 43). April snow cover extent in the Northern Hemisphere is strongly correlated with temperature in the region between 40 and 60 degrees N Latitude; this reflects the feedback between snow and temperature (IPCC 2007, p. 43).

The presence of snow on sea ice plays an important role in the Arctic climate system (Powell et al. 2006). Arctic sea ice is covered by snow most of the year, except when the ice first forms and during the summer after the snow has melted (Sturm et al. 2006). Warren et al. (1999, cited in IPCC 2007 Chapter 4) analyzed 37 years (1954–1991) of snow depth and density measurements made at Soviet drifting stations on multi-year Arctic sea ice. They found a weak negative trend for all months, with the largest being a decrease of 8 cm (3.2 in) (23 percent) in May.

Precipitation

The Arctic Climate Impact Assessment (2005) concluded that ''overall, it is probable that there was an increase in arctic precipitation over the past century.'' An analysis of data in the Global Historical Climatology Network (GHCN) database indicated a significant positive trend of 1.4 percent per decade (ACIA 2005) for the period 1900 through 2003. New et al. (2001, cited in ACIA 2005)) used uncorrected records and found that terrestrial precipitation averaged over the 60 degree to 80 degree N latitude band exhibited an increase of 0.8 percent per decade over the period from 1900 to 1998. In general, the greatest increases were observed in autumn and winter (Serreze et al. 2000). According to the ACIA (2005) calculations: (1) during the Arctic warming in the first half of the 20th century (1900–1945), precipitation increased by about 2 percent per decade, with significant positive trends in Alaska and the Nordic region; (2) during the two decades of Arctic cooling (1946–1965), the high-latitude precipitation increase was roughly 1 percent per decade, but there were large regional contrasts with strongly decreasing values in western Alaska, the North Atlantic region, and parts of Russia; and (3) since 1966, annual precipitation has increased at about the same rate as during the first half of the 20th century. The ACIA report (2005) notes that these trends are in general agreement with results from a number of regional studies (e.g., Karl et al. 1993; Mekis and Hogg 1999; Groisman and Rankova 2001; Hanssen-Bauer et al. 1997; Førland et al. 1997; Hanssen-Bauer and Førland 1998). In addition to the increase, changes in the characteristics of precipitation have also been observed (ACIA 2005). Much of the precipitation increase appears to be coming as rain, mostly in winter and to a lesser extent in autumn and spring. The increasing winter rains, which fall on top of existing snow, cause faster snowmelt. Increased rain in late winter and early spring could affect the thermal properties of polar bear dens (Derocher et al. 2004), thereby negatively impacting cub survival. Increased rain in late winter and early spring may even cause den collapse (Stirling and Smith 2004).

According to the IPCC AR4 (2007, pp. 256–258), distinct upward trends in precipitation are evident in many regions at higher latitudes, especially from 30 to 85 degrees N latitude. Winter precipitation has increased at high latitudes, although uncertainties exist because of changes in undercatch, especially as snow changes to rain (IPCC 2007, p. 258). Annual precipitation for the circumpolar region north of 50 degrees N has increased during the past 50 years by approximately 4 percent but this increase has not been homogeneous in time and space (Groisman et al. 2003, 2005, both cited in IPCC 2007, p. 258). According to the IPCC AR4: ''Statistically significant increases were documented over Fennoscandia, coastal regions of northern North America (Groisman et al. 2005), most of Canada (particularly northern regions) up until at least 1995 when the analysis ended (Stone et al. 2000), the permafrost-free zone of Russia (Groisman and Rankova 2001) and the entire Great Russian Plain (Groisman et al. 2005, 2007).'' That these trends are real, extending from North America to Europe across the North Atlantic, is also supported by evidence of ocean freshening caused by increased freshwater run-off (IPCC 2007, p. 258).

Rain-on-snow events have increased across much of the Arctic. For example, over the past 50 years in western Russia, rain-on-snow events have increased by 50 percent (ACIA 2005). Groisman et al. (2003) considered rain-on-snow trends over a 50-year period (1950–2000) in high latitudes in the northern hemisphere and found an increasing trend in western Russia and decreases in western Canada (the decreasing Canadian trend was attributed to decreasing snow pack). Putkonen and Roe (2003), working on Spitsbergen Island, where the occurrence of winter rain-on-snow events is controlled by the North Atlantic Oscillation, demonstrated that these events are capable of influencing mean winter soil temperatures and affecting ungulate survival. These authors include the results of a climate modeling effort (using the earlier-generation Geophysical Fluid Dynamics Laboratory climate model and a 1 percent per year increase in CO_2 forcing scenario) that predicted a 40 percent increase in the worldwide area of land affected by rain-on-snow events from 1980–1989 to 2080–2089. Rennert et al. (2008) discussed the significance of rain-on-snow events to ungulate survival in the Arctic, and used the dataset European Center for Medium-range Weather Forecasting (ECMWF) European 40 Year (ERA40) Reanalysis (Uppala et al. 2005) to create a climatology of rain-on-snow events for thresholds that impact ungulate populations and permafrost. In addition to contributing to increased incidence of polar bear den collapse, increased rain-on-snow events during the late winter or early spring could also damage or eliminate snow-covered pupping lairs of ringed seals (the polar bear's principal prey), thereby increasing pup exposure and the risk of hypothermia, and facilitating predation by polar bears and Arctic foxes. This could negatively impact ringed seal recruitment.

Projected Changes in Arctic Sea Ice

Background

To make projections about future ecosystem effects that could result from climate change, one must first make projections of changes in physical